EASTERN REGIONAL RESEARCH CENTER
AGRICULTURAL RESEARCH SERVICE
UNITED STATES DEPARTMENT OF AGRICULTURE
600 E. MERMAID LANE
WYNDMOOR, PA 19038
(215) 233-6400

Title: Irradiation of Ready-to-Eat Foods at USDA'S Eastern Regional Research Center –2003 Update

Author(s): C. Sommers, X. Fan, B. Niemira, and K. Rajkowski

Citation: Radiation Physics and Chemistry (2004) 71: 511-514

Number: 7431

Business paper

Irradiation of ready-to-eat foods at USDA'S Eastern Regional Reasearch Center-2003 update

Christopher Sommers*, Xuetong Fan, Brendan Niemira, Kathleen Rajkowski

Eastern Regional Research Center, US Department of Agriculture, Agricultural Research Service, Food Safety Intervention Technologies Research Unit, 600 East Mermaid Lane, Wyndmoor, PA 19038, USA

Abstract

Ionizing radiation is a safe and effective method for eliminating bacterial pathogens from food products and disinfestation of fruits and vegetables. Since 1980 research has been conducted at USDA's Eastern Regional Research Center pertaining to the elimination of food-borne pathogens from meat, poultry, fruit and vegetable products. Recent work has focused on elimination of pathogens such as *Escherichia coli O157:H7*, *Salmonella* spp., and *Listeria monocytogenes* from ready-to-eat (RTE) food products including hot dogs, bologna, lettuce, cilantro, sprouts and seeds, and frozen vegetables. The ionizing radiation dose required to eliminate those pathogens from RTE foods has been found to be commodity, formulation and temperature dependent. The need to eliminate bacterial pathogens from RTE food products must always be balanced with the maintenance of product quality. In addition to determining the effective ionizing radiation doses required for pathogen elimination the effects of irradiation on product chemistry, nutritional value and organoleptic quality have also been determined. A review of the studies conducted at USDA's Eastern Regional Research Center in 2002 and 2003 is presented in this article.

Keywords: Ready-to-eat; Irradiation; Food chemistry; Pathogen elimination

1. Irradiation of ready-to-eat meats

Listeria monocytogenes (Lm) is a frequent contaminant on ready-to-eat (RTE) meat products and has been responsible for a number of food-borne illness outbreaks and product recalls (Anonymous, 1998). Because of the high mortality rate associated with listeriosis, approximately 20% in susceptible populations, *Lm* is given zero tolerance in ready-to-eat meat products in the United States by the USDA's Food Safety Inspection Service (Mead et al., 1999; USDA, 1989). In the last 5 years over 90 million pounds or RTE meats have been recalled, in the United States, due to contamination with *Lm* (USDA FSIS, 2003).

A number of studies have been conducted to determine the radiation resistance of *Lm* on RTE meats. The ionizing radiation dose required to eliminate 5 $\log_{10}$, or 99.999%, of *Lm* from frankfurters, bologna, ham and deli turkey meat ranged from 2.45 to 3.75 kGy depending on type and product formulation (Sommers et al., 2003; Foong et al., 2002; Sommers and Thayer, 2000).

Subsequent studies focused on the ability of additives to (1) increase the sensitivity of *Lm* to ionizing radiation and (2) to inhibit the post-irradiation growth of *Lm*. The antimicrobial compounds sodium diacetate and potassium lactate, both of which are approved for use in RTE meat, can inhibit the growth of *Lm* during long-term refrigerated storage. Sodium diacetate (0.5%), when incorporated into the formulation of beef bologna increased the radiation sensitivity of *Lm* by 10% and inhibited growth of radiation damaged *Lm* for 6 weeks refrigerated storage at 9°C (Sommers and Fan, 2003; Sommers et al., 2003). In contrast, lactate, while it inhibits the growth of *Lm*, does not increase its radiation

*Corresponding author.

sensitivity. The most functional additive proved to be a mixture of 0.15% sodium diacetate and 2% potassium lactate incorporated into beef bologna. The radiation sensitivity of *Lm* increased by 18% when suspended in that product and post-irradiation growth of *Lm* was prevented for 8 weeks refrigerated storage at 9°C (Sommers et al., 2003). The authors concluded that ionizing radiation in combination with diacetate and lactate mixtures can inactivate *Lm* in fine emulsion sausage products and prevent the growth of radiation damaged *Lm* for at least 2 months during refrigerated storage.

2. Elimination of pathogens from fruits and vegetables

The application of low dose (<3 kGy) irradiation to a variety of fruits, vegetables and juices to eliminate human pathogens is an area of active research (Prakash et al., 2000a, b). An outbreak strain of *Escherichia coli* (*E. coli*) O157:H7 was inoculated onto four closely related but structurally distinct types of lettuce: Boston, Iceberg, Green Leaf and Red Leaf (Niemira et al., 2002a). The bacteria were inoculated either onto the surface of cut leaf pieces, or into a homogenized leaf suspension. Samples were gamma-irradiated and the radiation sensitivity of the inoculated bacteria was expressed as D10 (the amount of ionizing radiation necessary to reduce the bacterial population by 90%, in kGy). Recovery of bacteria from nonirradiated leaf pieces was also measured. When inoculated on the leaf surface, *E. coli* O157:H7 had a significantly greater radiation sensitivity on Red leaf (D10 = 0.12 kGy) and Green leaf (0.12 kGy) than on Iceberg (0.14 kGy) or Boston (0.14 kGy). Significantly fewer bacteria were recovered from the surface of Iceberg vs. the other types examined. When *E. coli* O157:H7 was inoculated into a homogenized leaf suspension, in order to simulate internalization of the pathogen, the radiation sensitivity was significantly greater on Iceberg (0.09 kGy) than on Green leaf (0.33 kGy), Boston (0.33 kGy) or Red leaf (0.34 kGy), a difference of approximately 350%. The authors concluded that a radiation dose of 1.0 kGy can effectively inactivate *E. coli* O157:H7 in lettuce.

In a similar study using another leafy salad vegetable, endive, leaf pieces and leaf homogenate were inoculated with *Lm* or *L. innocua*, a nonpathogenic surrogate bacterium (Niemira et al., 2003). The radiation sensitivities of the two strains were found to be similar (0.21 kGy), although *L. innocua* was more sensitive to the type of suspending leaf preparation. During refrigerated storage following irradiation (4°C), the population of *Lm* on inoculated endive was briefly suppressed by 0.42 kGy, a dose calibrated to achieve a 99% reduction. However, after 5 days the pathogen regrew until it exceeded the bacterial levels on the control after 19 days in storage (4°C). Treatment with 0.84 kGy, equivalent to 99.99% reduction, suppressed *Lm.* throughout the course of refrigerated storage. The authors concluded that a radiation dose of 0.84 kGy would be sufficient to control *Lm* in endive.

Four frozen vegetables (broccoli, corn, lima beans and peas) were gamma irradiated at various sub-freezing temperatures ranging from −5°C to −20°C to determine (a) the radiation sensitivity of an inoculated outbreak strain of *Lm.* (b) the effect of changing irradiation conditions i.e. temperature, and (c) the effect of the recommended radiation dose on the texture and color of irradiated frozen vegetables (Niemira et al., 2002b). The D10 for *Lm.* differed significantly among the vegetables at each irradiation temperature. D10 increased significantly with decreasing temperature for all vegetables, with each vegetable showing a different pattern of response. At −20°C, radiation doses sufficient to achieve a 5-log 10 kill (3.9–4.6 kGy) caused significant softening of peas and broccoli stems, but not of corn or lima beans. Lower doses of comparable antimicrobial efficacy delivered at −5°C (2.5–3.1 kGy) did not cause significant changes in texture in any vegetable.

Food-borne illness outbreaks associated with the consumption of raw sprouts is often due to proliferation of pathogens during the sprouting process resulting from use of contaminated seeds (NACMCF, 1999). Irradiation of seeds for the purpose of pathogen reduction of sprouts is permitted to radiation doses up to 8 kGy (US DHHS, 1999). Rajkowski et al. (2003) found the D10 values of *E. coli* O157:H7 ranged from 1.11 to 1.43 kGy on broccoli seeds. D10 values for *Salmonella* spp. on broccoli seeds ranged from 0.74 to 1.11 kGy. In the same study the percent germination of broccoli seeds decreased linearly with radiation dose from 97% at 0 kGy to 88% at a dose of 4 kGy. Yield ratios (g sprouts/g seeds) decreased from 12.3% at 0 kGy to 7.2% at 4 kGy. Sprout length and thickness decreased from 30 and 0.73 mm, respectively, at 0 kGy to 7 and 0.45 mm, respectively, at 4 kGy. It was concluded that a radiation dose of 3 kGy for broccoli seeds was acceptable in terms of quality, however, the low $\log_{10}$ reduction of the pathogens at that dose (approximately 2.7 $\log_{10}$) would require other intervention treatments to be used in combination with ionizing radiation.

3. Chemistry and quality of irradiated vegetables

A study was conducted to investigate the upper dose limit of irradiation on quality of fresh-cut iceberg lettuce (Fan and Sokorai, 2002a). Fresh-cut iceberg lettuce packaged in film bags was exposed to 0, 1, 2, 3 or 4 kGy gamma radiation and stored at 3°C for 14 days. CO_2 levels were higher and O_2 levels were lower in packages containing irradiated lettuce than those of non-irradiated lettuce through most of the storage period. Compared to nonirradiated lettuce, total ascorbic acid (ascorbic acid plus dehydroascorbic acid) content and firmness were not significantly influenced by irradiation at 1 or 2 kGy. Overall visual appearance of lettuce irradiated at 1 or 2 kGy was the best. The better quality may be related to high CO_2 and low O_2 levels observed in the irradiated samples. Electrolyte leakage of lettuce increased with higher radiation doses and was correlated ($R^2 = 0.99$) to soggy appearance. The leakage of lettuce irradiated at 2 kGy and higher doses was significantly higher than that of nonirradiated lettuce. Irradiation at dose of 1 kGy of fresh-cut lettuce in modified atmosphere packages is feasible for safety enhancement and quality improvement.

In another study, we investigated the synergetic effects of irradiation and warm water dipping on quality of lettuce. Fresh-cut iceberg lettuce dipped in either 5°C or 47°C water for 2 min was packaged in modified atmosphere film bags and then exposed to 0, 0.5, 1 or 2 kGy gamma radiation (Fan et al., 2003a). Dipping cut lettuce in 47°C water for 2 min prior to irradiation inhibited the irradiation-induced accumulation of antioxidants and phenolics. Irradiation at 2 kGy increased cellular leakage and sogginess of cut lettuce dipped in both temperatures. Samples irradiated at 0.5 and 1 kGy had similar firmness, vitamin C, and antioxidant content as the controls after 14 and 21 days of storage except 1 kGy samples dipped at 47°C had lower antioxidant content than controls at 14 days of storage. Lettuce dipped at 47°C and irradiated at 0.5 and 1 kGy had better overall visual quality and less tissue browning than corresponding irradiated samples dipped at 5°C. Our results suggest lettuce treated with warm water and irradiated at 0.5 or 1 kGy had the best sensory quality without significant loss in texture, vitamin C or total antioxidants.

Consumption of salsas and dishes containing cilantro has been linked to several recent outbreaks of food borne illness due to contamination with human pathogens. Ionizing irradiation can effectively eliminate foodborne pathogens from various vegetables including cilantro. However, the effect of irradiation on quality of fresh cilantro is unknown. Studies have been conducted to investigate the effect of irradiation on sensory quality and volatile compounds of fresh cilantro leaves (Fan et al., 2003b; Fan and Sokorai, 2002b). Fresh cilantro leaves (*Coriandrum sativum*) were irradiated with 0, 1, 2, or 3 kGy gamma radiation and then stored at 3°C up to 14 days. Volatile compounds, aroma, appearance, nutritional, textural, and microbiological quality attributes of fresh cilantro was measured at 0, 3, 7 and 14 days after irradiation. Most of the volatile compounds identified were aldehydes. Decanal and (*E*)-2-decenal were the most abundant compounds, accounting for more than 80% of the total amount of identified compounds. The amounts of linalool, dodecanal and (*E*)-2-dodecenal in irradiated samples were significantly lower than those in non-irradiated samples at day 14. However, the most abundant compounds (decanal and (*E*)-2-decenal) were not consistently affected by irradiation. During storage at 3°C, the amount of most aldehydes peaked at 3 days and then decreased afterward. Irradiation at doses up to 2 kGy did not significantly influence aroma, color or overall visual quality. Although firmness of cilantro were reduced by irradiation at day 0, there was no significant difference among treatments after 3, 7 and 14 days of storage at 3°C. Irradiation did not have a consistent effect on antioxidant power or phenolic content during the 14-day storage. In contrast, vitamin C content was lower at day 14 in samples irradiated at 2 and 3 kGy. Cilantro irradiated at 3 kGy developed higher decay rate and off-odor scores than other samples after 14 days of storage. The total aerobic plate count of irradiated cilantro was significantly lower than that of nonirradiated controls immediately after irradiation and during the entire storage period. Overall, our results show that irradiation at doses of 2 kGy or less generally did not negatively impact volatile compounds or quality attributes of cilantro, but significantly reduced the population of bacteria on cilantro.

References

Anonymous, 1998. Multistate outbreak of listeriosis-United States, 1998. Morbid Mortal. Wkly. Rep. 47, 1085–1086.

Fan, X., Sokorai, K., 2002a. Sensorial and chemical quality of gamma irradiated fresh-cut iceberg lettuce in modified atmosphere packages. J. Food Prot. 65, 1760–1765.

Fan, X., Sokorai, K., 2002b. Changes in volatile compounds of gamma irradiated fresh cilantro leaves during cold storage. J. Agric. Food Chem. 50, 7622–7627.

Fan, X., Toivonen, P.M.A., Rajkowski, K.T., Sokorai, K., 2003a. Warm water treatment in combination with modified atmosphere packaging reduced undesirable effects of irradiation on the quality of fresh-cut iceberg lettuce. J. Agric. Food Chem. 51, 1231–1236.

Fan, X., Niemira, B.A., Sokorai, K.J.B., 2003b. Sensorial, nutritional and microbiological quality of fresh cilantro leaves as influenced by ionizing irradiation and storage. Food Res. Int. 36, 713–719.

Foong, S.C., Gonzalez, G.C., Dickson, J.S., 2002. Marginal safety of irradiation dosage for reduction and post-irradiation survival of *Listeria monocytogenes* in ready-to-eat (RTE) meats. Abstract P043. International Association for Food Protection Annual Meeting, San Diego, CA.

Mead, P.S., Slutsker, L., Dietz, V., McCaig, L.F., Bresee, J.S., Shapiro, C., Griffin, P.M., Tauxe, R.V., 1999. Food-related illness and death in the United States. Emerging Infect. Dis. 5, 607–625.

NACMCF 1999. Microbiological safety evaluations and recomendations on sprouted seeds. http://vm.cfsan.fda.gov/~mow/sprouts2.html.

Niemira, B.A., Sommers, C.H., Fan, X., 2002a. Suspending lettuce type influences recoverability and radiation sensitivity of *E. coli* O157:H7. J. Food Prot. 65, 1388–1393.

Niemira, B.A., Fan, X., Sommers, C.H., 2002b. Irradiation temperature influences product quality factors of frozen vegetables and radiation sensitivity of inoculated *Listeria monocytogenes*. J. Food Prot. 65, 1406–1410.

Niemira, B.A., Fan, X., Sokorai, K.J.B., Sommers, C.H., 2003. Ionizing radiation sensitivity of *Listeria monocytogenes* and *L. innocua* inoculated on endive (*Cichorium endiva*). J. Food Prot. 66, 993–998.

Prakash, A., Guner, A.R., Caporaso, F., Foley, D.M., 2000a. Effects of low-dose gamma irradiation on the shelf life and quality characteristics of cut Romaine lettuce packaged under modified atmosphere. J. Food Sci. 65, 549–553.

Prakash, A., Inthajak, P., Huibregtse, H., Caporaso, F., Foley, D.M., 2000b. Effects of low-dose gamma irradiation and conventional treatments on shelf life and quality characteristics of diced celery. J. Food Sci. 65, 1070–1075.

Rajkowski, K.T., Boyd, G., Thayer, D.W., 2003. Irradiation D-values for *Escherichia coli* O157:H7 and *Salmonella* sp. on inoculated broccoli seeds and effects of irradiation on broccoli sprout keeping quality and seed viability. J. Food Prot. 66, 760–766.

Sommers, C.H., Thayer, D.W., 2000. Survival of surface-inoculated *Listeria monocytogenes* on commercially available frankfurters following gamma irradiation. J. Food Safety 20, 127–137.

Sommers, C.H., Fan, X., 2003. Irradiation (gamma) of fine emulsion sausage that contained sodium diacetate. J. Food Prot. 66, 819–824.

Sommers, C.H., Fan, X., Niemira, B.A., Sokorai, K., 2003. Radiation (gamma) resistance and post-irradiation growth of *Listeria monoctytogenes* suspended in beef bologna that contained sodium diacetate and potassium lactate. J. Food Prot. 66, 2051–2056.

USDA, 1989. Revised policy for controlling *Listeria monocytogenes*. Food Safety and Inspection Service, US Department of Agriculture, Washington, DC. Federal Register, Vol. 54, pp. 22345–22346.

USDA, 2003. Meat and Poultry Product Recalls: News releases and information for consumers. USDA. FSIS. Washington, DC 20250. http://www.fsis.usda.gov/OA/ recalls/ rec_all.htm.

US Department of Health, Human Services, 1999. Consumers advised of risks associated with raw sprouts. Press Release No. P99-13, Washington, DC, July 9.

Further reading

Niemira, B.A., Sommers, C.H., Boyd, G., 2000. Irradiation inactivation of four *Salmonella* serotypes in orange juices with various turbidities. J. Food Prot. 64, 614–617.

Rajkowski, K.T., Thayer, D.W., 2000. Elimination of *Salmonella* spp and strains of *E. coli* O157:H7 by gamma irradiation of inoculated sprouts. J Food Prot. 63, 871–875.

Rajkowski, K.T., Thayer, D.W., 2001. Alfalfa seed germination and yield ratio and alfalfa sprout microbial keeping quality following irradiation of seeds and sprouts. J. Food Prot. 64, 1988–1995.